Perspectives in Vascular Surgery and Endovascular Therapy
Volume 18, Number 2
June 2006 141-145
© 2006 Sage Publications
10.1177/1531003506293451
http://pvs.sagepub.com
hosted at
http://online.sagepub.com

Upper Extremity Arterial Combat Injury Management

Michael A. Weber, MD, Charles J. Fox, MD, Eric Adams, MD, Rob D. Rice, Reagan Quan, MD, Mitchell W. Cox, MD, and David L. Gillespie, MD

Traumatic hemorrhage and vascular injury management have been concerns for both civilian and military physicians. During the 20th century, advances in technique allowed surgeons to focus on vascular repair, restoration of perfusion, limb salvage, and life preservation. Military surgeons such as Makins, DeBakey, Hughes, Rich, and others made significant contributions to the field of surgery in general and vascular surgery in particular. Casualties from combat in Afghanistan and Iraq confront physicians and surgeons with devastating injuries. The current generation of providers is challenged with applying contemporary care while expanding upon the lessons taught by our predecessors. The objective of this report is to review the historical experience with managing military upper extremity arterial injuries and compare that experience with current management.

Keywords: vascular trauma; management; upper extremity; arterial

World War I

Makins studied the British experience with vascular injuries during World War I.[1] From 2 series with complete information, he analyzed a total of 992 arterial war injuries in an era before lateral suture repair was popular. Among 108 axillary artery injuries, only 3 (2.7%) developed gangrene. Brachial injuries were identified in 200 patients, and gangrene developed in 8 (4.0%). Forearm arteries were not included in his analysis. These results were much better than the results from the lower extremity with 20% gangrene from femoral artery injury and 35% gangrene from popliteal artery injury. Makins made several important observations. He noted, "The associated contusion may have lowered the vitality of the margins of the wound to a degree which ocular inspection may be incapable of determining. The injury may be extensive within the lumen. The intima may not only have suffered by contusion but that, as a result of stretching by displacement the intima may be fissured at a considerable distance from the wound itself."[1] Based on these observations, he developed 4 management recommendations. "Bleeding vessels in an open wound are always to be ligated at the earliest possible moment. When injured vessels, and especially those of large caliber, are visible in open wounds they are to be ligated whether bleeding or not. The vessel should be ligated above and below the thrombosed segment and later excised. If the wound is through and through and there is no expanding hematoma or evidence of ischemia, then dealing with a hematoma or pseudoaneurysm is preferred over attempted primary repair in the front line."[1]

World War II

DeBakey added to the management of vascular war wounds through his World War II analysis.[2]

From the Department of Surgery, Vascular Surgery Service, Walter Reed Army Medical Center, Washington, DC (MAW, CJF, EA, RDR, RQ, MWC, DLG); and the Division of Vascular Surgery, Uniformed University of the Health Sciences, Bethesda, Maryland (MAW, CJF, EA, RQ, MWC, DLG).

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

Address correspondence to: David L. Gillespie MD, FACS, COL, MC, USA; Chief and Program Director, Vascular Surgery Service, Associate Professor of Surgery, Walter Reed Army Medical Center/USUHS, Washington DC; tel: 202-782-9928; fax: 202-782-3198; e-mail: david.gillespie@na.amedd.army.mil.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUN 2006		**00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Upper Extremity Arterial Combat Injury Management	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Walter Reed Army Medical Center,Department of Surgery,6900 Georgia Ave NW,Washington,DC,20307**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

Additionally, he identified what he termed medico-military problems in treatment of acute arterial injuries. Generally, the problems were time lag, practical difficulties, status of the casualty, associated wound site, type of injury, and infection. He wrote: "Although the restoration of the flow of blood through the original channel is the desideratum; unfortunately, it can only be achieved in limited numbers in civilian practice and even less in military practice."[2] In his series of 2471 arterial injuries, there were 74 axillary artery injuries associated with a 43.2% limb loss. Brachial artery injuries above the profunda occurred in 97 patients with a 55.7% limb loss, but there were 209 injuries below the profunda with a 25.8% limb loss. Although the percentages were much higher than those for Makins' data, DeBakey's data included patients who had extensive infections and mangled extremities. The data demonstrated the significance of an intact profunda on overall limb salvage rate from upper extremity arterial injury.

Vietnam

Rich's analysis of the Vietnam Vascular Registry evaluated more contemporary management techniques of arterial injuries.[5-7] At the time, his preliminary report was published, complete records were available for 332 injuries. There were 20 axillary artery injuries treated in Vietnam: 2 lateral suture repairs, 6 end-to-end anastomoses, and 12 saphenous vein grafts. Thrombosis occurred in 8 repairs: 4 vein grafts, 3 end-to-end repairs, and one lateral suture repair. Four patients with known thromboses were asymptomatic, as were two patients with stenotic repairs. Only one vascular repair failure required amputation. The brachial artery was injured in 103 cases with 97 initial repairs performed in Vietnam. Among the repairs were 2 lateral repairs, 57 end-to-end anastomoses, and 32 vein grafts. Thrombosis occurred in 1 lateral suture repair (50% patency), 10 end-to-end anastomoses (82% patency), and 5 vein grafts (84% patency). Nine (56%) patients with known thrombosis were asymptomatic. Amputation was necessary in 3 (2.9%) patients due to infection. Forearm arteries were not part of the registry.

Operation Enduring Freedom and Operation Iraqi Freedom

All US military casualties evacuated to Walter Reed Army Medical Center (WRAMC) from December 2001 through May 2005 were screened for vascular injuries. Patients with vascular injuries were evaluated by a senior vascular surgeon. These patients were prospectively entered into a clinical database and the data was retrospectively reviewed. Basic demographic data collected included patient age, country where injured, and date of injury.

Specific patterns of injury were documented, noting the mechanism, site, vessel injured, associated trauma, and initial management. Vascular repairs were analyzed by the type of repair performed, and the use of autologous vein grafting was compared with the use of prosthetic grafting. The initial outcomes, including patency and viability, were documented. Early patency was defined as patency at the initial evaluation at WRAMC which occurred between 3 and 14 days. Arteriographic findings, including occult injury and the use of catheter-based techniques, were documented.

Demographics

During the 42-month study period, 3057 soldiers were evacuated to WRAMC for medical evaluation. Of those, 1177 (39%) sustained injuries. Known or suspected vascular injuries occurred in 304 (26%) of which 58 (20%) had injuries to the upper extremity arteries. These 58 patients comprise our study group. Four were injured in Afghanistan during Operation Enduring Freedom (OEF), and 54 were injured during Operation Iraqi Freedom (OIF). Of the 58 patients, 51 (88%) were male and 7 (12%) were female. The average age was 26.7 years (range, 19-55 years).

Mechanism of Wounding

The majority of injuries (74%) were from fragment-producing weapons. The weapons include grenades, mines, artillery, and improvised explosive devices (IEDs). High-velocity gunshot wounds caused upper extremity vascular injuries in 17% patients. Nonbattle injury (NBI) to the upper extremity arteries resulted from four motor vehicle accidents and one tiger bite: 9% of patients (Table 1).

Table 1. Mechanisms of Traumatic Injury

Mechanism	No.
Fragmentation	43 (74%)
Gunshot wounds	10 (17%)
Nonbattle injury	5 (9%)

Table 2. Management by Anatomic Location

Artery	Ligation	Lateral Suture	End-to-end	Vein Graft	Prosthetic Graft	Endovascular	Total
Axillary	1	3	0	2	1	1	8
Brachial	1	10	1	18	1	2	33
Radial	8	1	0	6	0	1	16
Ulnar	2	1	0	3	0	0	6
Total	12	15	1	29	2	4	63

Table 3. Associated Amputation Percentage

Artery	Ligation	Failed Graft
Axillary	0	0
Brachial	0	5
Radial	0	0
Ulnar	0	0

Table 4. Early Lateral Repair Patency

Artery	Vietnam	OEF/OIF
Axillary	50%	100%
Brachial	50%	100%
Radial	N/R	100%
Ulnar	N/R	100%

Table 5. Early Vein Graft Patency

Artery	Vietnam	OEF/OIF
Axillary	67%	50%
Brachial	85%	72%
Radial	N/R	50%
Ulnar	N/R	67%

Anatomic Location of Wounds

The 58 patients with upper extremity arterial wounds presented with a total of 63 distinct arterial injuries. The axillary artery was injured in 8 patients (13%). The brachial artery was injured in 33 patients (52%). The radial artery was injured in 16 patients (25%), and the ulnar artery was injured in 6 patients (10%).

Wound Management by Location

Axillary artery injuries were managed with a variety of techniques (Table 2). Of these 8 injuries, 1 (12.5%) was managed with ligation to control hemorrhage in a traumatically amputated arm (Table 3). There were no end-to-end repairs and 3 (37.5%) injuries managed with lateral repairs with a 100% early patency (Table 4). Interposition grafting was performed for 3 axillary artery wounds (37.5%). Two (67%) of these grafted wounds were managed with reversed saphenous vein grafts with a 50% early patency (Table 5). The thrombosed graft was successfully revised at Walter Reed Army Medical Center (WRAMC). Polytetrafluoroethylene (PTFE) was used in 1 (33%) of the grafted wounds and was thrombosed at presentation. The graft was excised and replaced with a saphenous vein graft at WRAMC. Endovascular management with a Viabahn stent graft was used to manage 1 (12.5%) of the axillary artery injuries with a 100% early patency (Table 6).

Brachial arteries were injured 33 times in this series. Of these patients, 1 (3%) was successfully managed with primary ligation. One patient (3%) was managed with end-to-end anastomosis with 100% early patency. Lateral repairs were performed to manage 10 (30%) brachial artery injuries with a 100% early patency. Interposition grafting was used to manage the brachial artery injury in 19 patients: 18 (95%) with reversed saphenous vein and 1 (5%) with 6mm PTFE. Five of the saphenous vein grafts were thrombosed—a 72% early patency rate. Of the 5 patients with thrombosed vein grafts, 4 (80%) were asymptomatic and 1 (20%) was symptomatic. Ultimately, the 4 asymptomatic patients underwent successful revision. The symptomatic patient also had a mangled hand and forearm and was ultimately managed with below-elbow amputation. The 1 PTFE graft was exposed, thrombosed, presumed infected, and ultimately excised and replaced by a vein graft. Endovascular techniques were successfully used to manage 2 arterial injuries: 1 thrombectomy and 1 stent.

Radial arteries were injured in 16 patients. Ligation was used in 8 (50%) patients, all of whom were asymptomatic. Primary repair was used for 1 patient who had 100% early patency. Interposition vein grafting was used to manage 6 injuries and no PTFE grafts were used. Three of the radial artery vein

Table 6. Early Patency Percentage

Artery	Lateral Suture	End-to-end	Vein Graft	Prosthetic Graft	Endovascular
Axillary	100	n/a	50	0	100
Brachial	100	100	72	0	100
Radial	100	n/a	50	n/a	100
Ulnar	100	n/a	67	n/a	n/a

grafts were thrombosed and asymptomatic: 50% early patency. Endovascular technique, thrombectomy, was successfully used in 1 patient.

Ulnar arteries were injured in 6 patients. Ligation was used in 2 (33%) patients, all of whom were asymptomatic. Primary lateral repair was used in 1 patient (17%) with 100% early patency. Saphenous vein grafts were used in 3 (50%) patients with 67% early patency. The occluded vein graft was asymptomatic. There were no PTFE grafts and no endovascular techniques used.

Conclusion

Historical data demonstrates that arterial injuries to the upper extremity have better results than arterial injuries to the lower extremities.[1,3,7] Furthermore, upper extremity arterial injuries below the profunda have better results than injuries above the profunda.[3] All these retrospective reviews lack the statistical power and long-term follow-up to make definitive management recommendations, but they suggest management strategies that may serve for the basis of further study and treatment.

Appropriate upper extremity arterial injuries managed with lateral repair and end-to-end anastomosis can be expected to have excellent patency. Wounds with more extensive arterial injury can be successfully managed with grafting where vein is superior to PTFE. If grafting is used, it should be covered and routed outside the zone of injury if possible. In highly selected patients, thrombectomy and stent grafting can produce excellent patency results.

A patent profunda brachial artery may provide adequate perfusion to maintain viability of the arm and hand when the brachial artery is interrupted. Based on Makins', DeBakey's, and Rich's observations, we suggest the following strategy to manage brachial artery injuries in the setting of war and poly-trauma. With the brachial artery temporarily occluded, hand perfusion is assessed. If a palpable pulse or audible Doppler signal is present in the radial or ulnar arteries, then the brachial artery injury may be ligated and arterial repair deferred. If adequate perfusion is not present, then a vein graft outside the zone of injury should be performed. If the patient is vein-limited either from trauma or previous operation, then a PTFE graft can be used to restore perfusion with the expectation of poor early patency. However, the temporary PTFE graft could serve as a sutured shunt until definitive vein grafting could be performed. This strategy conserves the vein for use when better graft patency could be expected.

Forearm arterial injuries may be managed by ligation with low rates of critical ischemia. In the OEF-OIF study, no patients in either the forearm artery ligation group or the failed forearm bypass group required an amputation.

The data from this study show that ligation of upper extremity arterial injuries do not invariably lead to critical ischemia. Overall, 19% of wounds were successfully managed with ligation. Lateral repairs of tangential upper extremity arterial injuries were associated with 100% early patency. End-to-end anastomosis was only used to manage 1 injury. This technique is most appropriate for wounds with limited zones of injury such as stab wounds or low-velocity missile wounds. In this series, the majority of wounds were from high-energy fragmentation associated with extensive soft tissue disruption. Upper extremity grafting was used to restore perfusion in patients with extensive segments of arterial injury. Overall, there were 31 grafts performed. Twenty-nine vein grafts had a 65% early patency and 2 PTFE grafts had a 0% early patency. Despite the rather poor patency results, only 1 patient with a failed bypass and a mangled extremity required amputation. New technologies and devices will be adapted for the treatment of wartime injuries. Endovascular techniques were successfully used in 4 highly selected patients with an overall 100% early patency. Recently, the use of temporary vascular shunts, as described in DeBakey's analysis, has regained popularity, although their use was not documented in any of the patients in this series.[3]

References

1. Makins GH. *History of the Great War Based on Official Documents. Medical Services Surgery of the War.* Vol. II. London: His Majesty's Stationery Office, 1922:chapter VI.
2. DeBakey ME. History, the torch that illuminates: lessons from military medicine. *Mil Med.* 1996;161: 711-716.
3. DeBakey ME, Simeone, MC. Battle injuries of the arteries in World War II. *Ann Surg.* 1946;APR:534-579.
4. DeBakey ME. Military surgery in World War II, a backward glance and a forward look. *N Engl J Med.* 1947;236: 341-350.
5. Rich NM, Baugh JH, Hughes CW. Significance of complications associated with vascular repairs performed in Vietnam. *Arch Surg.* 1970;100:646-651.
6. Rich NM. Vascular trauma in Vietnam. *J Cardiovasc Surg (Torino)* 1970;11:368-377.
7. Rich NM, Hughes CW. Vietnam vascular registry: a preliminary report. *Surgery.* 1969;65:218-226.